1.8 Environmental compliance personnel shall demonstrate a familiarity level knowledge of force to geophysical properties.

Supporting Knowledge and/or Skills

a. Define the following:

- Force
- Weight

Geophysics is the physical study of the earth and its atmosphere. Geophysics applies physical disciplines (e.g., seismology, meteorology, hydrology) and their related physical and analytical methods to better understand the nature of the earth.[1] Related to the study of geophysics is the study of mechanics. Mechanics studies forces and motions. The following terms are related to the study of mechanics.

Force

Force is a vector quantity that generally produces a change in the state of rest or motion of a body. It produces an acceleration in the direction of its application. It is the direction and magnitude of the force that makes force a vector quantity. Newton’s second law of motion defines the concept of force as shown in the formula:

$F = ma$.

where:

“F” is the force on an object and can be measured in units called “Newtons” which are kilogram x meters/second^2 (kg*m/sec^2)

“m” is the mass of the object and can be measured in kilograms (Kg)

“a” is the acceleration of the object, which is the change in velocity over time; measurement of acceleration is similar to the measurement of velocity but with an accounting of the change over time; velocity is measured in distance and time as meters per second (m/sec) and acceleration is measured in meters per second per second (m/sec^2).

Force can be characterized by its points of application, its magnitude, and its direction. Concentrated force, for example, is the application of force over a relatively small area. In other words, force is an external agency that is capable of changing a body’s state of rest or motion.[1]

Force is exerted on rock masses in nature in a variety of ways. Forces within the earth are transmitted to the surface and near surface rocks and cause deformation of those rocks. A downward vertical force results from the weight or load of the overlying rock mass. This is balanced by an equal upward force exerted by the buoyancy of the earth's interior. The downward force is reduced by removal of the load by erosion of overlying rocks or melting of glacial ice. The buoyant forces lift the resulting surface to higher elevations in a process of isostatic readjustment. Lateral forces may be exerted when tectonic plates collide. In these cases, rock may undergo compressional forces. An example is the Himalayan Mountains that are being compressed and uplifted as a result of the Indianian Plate colliding and moving under the Asian Plate. In other cases, rocks may experience tensional forces when tectonic plates move away from each other. An example is the Rift Valley which is developing in Africa as a result of movement of the plates beneath that continent. Shear forces may be exerted when tectonic plates move past each other. An example is the San Andres Fault system in California that results from differential movement in the Pacific and North American plates.

Weight

Weight, also related to the concept of force, can be defined as the force of attraction of the earth on a given mass. Weight, therefore, is measured in units of force (e.g., newtons). The concept of weightlessness is also related to force: weightlessness is a condition wherein a body is so far from another that it experiences negligible attraction, or gravitational force.[1] Weight is considered a special application of force: it is defined as the force exerted on a body by the gravitational attraction of the earth. Weight can also be defined mathematically as:

$W=mg$

where:

"W" is the weight of an object and can be measured in terms of the mass (m) times the force of gravity (g). At the surface of the earth the force of gravity is an acceleration measured in metric units of approximately 9.8 meters per sec^2 or in standard units of approximately 32 feet per sec^2.

Note that the mass of a body has the same value regardless of its location whether it is on the surface of the earth, the moon, or in space distant from any other body. The weight of a body, however, is dependent on the local acceleration of gravity, and is less when the local acceleration of gravity is less (e.g., the acceleration of gravity is lower on the moon than on earth and the weight of a given body is lower on the moon than it is on earth).

b. Define the following:

- Tensile force
- Compressive force
- Frictional force

Tensile Force

Tensile force is defined as a force applied to a body that tends to pull the body apart. An example is the force applied to a rope from a weight that is suspended by the rope. Tensile force is equal to the force exerted by the weight divided by the cross section area of the rope. Tensile strength is limited by the maximum tensile force that a material can support without deforming. Tensile force is described in terms of newtons per square meter or pounds per square inch[1].

Consolidated rocks near the surface of the earth are brittle substances and, when subjected to tension, generally fail by formation of tension cracks. Fractures usually form at right angles to the tensional forces[2].

Compressive Force

Compressive force, on the other hand, is an applied force that tends to compress the body to which it is applied. An example of a compressive force is the weight of an object that is supported by a rigid column such as the weight of a building that is supported by steel columns. The compressive force tends to compress the column. The compressive force equals the force applied to the column divided by the cross section area of the column. Compressive strength is limited by the maximum force that a body can withstand without deforming compressively.

Frictional Force

Frictional force is that force which resists relative movement between two bodies in a direction parallel to the contact between the bodies. Frictional forces may be dry frictional force between dry surfaces or fluid frictional force between layers of fluid that are moving differentially.

c. Explain the difference between a static-friction force and a kinetic-friction force.

Static-Friction Force

Static-friction force offers resistance to motion when some external force acting on one of two bodies in contact is insufficient to produce relative motion in one of the bodies in a direction parallel to the contact of the bodies. When the force is increased, if the limiting value for the static friction force is reached, relative motion occurs. Therefore, there exists a maximum value for the static friction force. For a given pair of surfaces, the maximum value for the static-friction force is nearly proportional to the normal force exerted by the surface on the bodies[3]. In the simple case, this normal force equals the weight of the overlying body that is resting on a horizontal surface between the bodies.

Kinetic-Friction Force

Kinetic-friction force, on the other hand, offers resistance to motion between two objects that are in relative motion in a direction parallel to their contact. Kinetic-friction force is lower than static-friction force for the same bodies. Therefore, the force required to initiate motion between two bodies is higher than the force required to maintain a constant rate of motion parallel to the contact between the bodies.[3]

d. ***State two factors that affect the magnitude of the friction force.***

Factors that affect the magnitude of the friction force between two bodies are (1) the nature of the contact (being rough or smooth), and (2) the normal force across the contact surface (proportional to the weight of the overlying block). The material of which the bodies are made (certain materials offer lower frictional forces than other materials) will also affect the magnitude of the frictional force. Frictional forces are approximately independent of the area of the contact between the bodies.

Frictional forces play a role in movement of rocks in response to tectonic forces within the earth. Tectonic forces build within the rocks at depth and near the earth surface from a variety of events such as relative movement of the plates that make up the earth's crust. These forces ultimately reach the static-friction force of existing faults in rocks of the crust or the compressive or tensile strength of these rocks. At that point, the relative movement of the rocks occur. Rocks experience relative movement across the plane of the fault and continue to move as long as the tectonic force exceeds the kinetic-friction force along the fault plane. This relative movement is an earthquake. When the tectonic forces fall below the kinetic-friction force relative movement along the fault ceases. Some tectonic force may remain within the rocks, but it is probably below the kinetic-friction force. The tectonic forces may build due to the continued relative movement of the crustal plates or other events. The tectonic forces will continue to build until they once again reach the static-friction force and another earthquake results.

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[1] Uvarov, E.B. and A. Isaacs, *Dictionary of Science*, 6th ed., Bungay, Suffolk, England: The Chaucer Press, Ltd., 1986.

[2] Billings, Marland P., *Structural Geology*, 2nd ed., Prentice Hall, Englewood Cliffs, NJ, 1965.

[3] Sears, Frances W. & Mark W. Zemansky, *University Physics*, 3rd ed., Reading, MA, Addison-Wesley Publishing Co, Inc., 1964.

1.9 Environmental compliance personnel shall demonstrate a familiarity level knowledge of the principles and concepts of soil science.

Supporting Knowledge and/or Skills

a. List the different soil compositions and soil structures.

Soil with similar properties (composition) are grouped into soil classifications as follows:

- Alfisols are soils with clay translocations and deposition, with high base status;
- Aridisols are soils existing in a dry climate where salts and carbonates may have accumulated;
- Entisols are recently formed soils with a limited development of horizons (layers);
- Histosols classify the soils in peat bogs and fens;
- Inceptisols are young soils that possess few diagnostic features;
- Mollisols are temperate grasslands soils;
- Oxisols are highly weathered tropical soils;
- Spodosols are soils with substantial subsoil accumulation of humus and iron/aluminum oxides;
- Ultisols are soils with clay translocations and deposition, with low base status; and,
- Vertisols are swelling clay soils.[1]

Soil structure is a description of the grouping or arrangement of particles in soil and is important in determining its characteristics. Structure is strictly a field term descriptive of the gross, over-all aggregation or arrangement of the primary soil separates. Four primary types of soil structure are recognized: platy, prismlike, blocklike, and spheroidal. The mechanics of structure formation are exceedingly complicated and rather obscure. The nature and origin of the parent material are important factors as are the physical and biochemical processes of soil formation, particularly those resulting in the synthesis of clay and humus. Climate is also a prime consideration.[1]

b. Define humus and explain its role in chemical reactions in the soil.

Humus is partially decomposed organic matter that is only slightly soluble in water. Humus coats sand, clay, and silt particles to form topsoils, by binding these particles and contributing to the soil's structure. Humus usually possesses a negative electrical charge and tends to attract positively charged nutrient ions - potassium (K^+), calcium ($Ca2^+$), and ammonia ($NH4^+$).[1] Humus has a negative charge strong enough to counteract the leaching effect of rainwater as it passes through the topsoil layer, binding the nutrients in a location accessible to plant roots. Pesticides that form cations (positively charged ions) also bond with the humus layer in a process called adsorption, decreasing their concentration in solution (and ultimately the groundwater). In addition, humus limits the solubility of certain metal cations, attenuating the migration of these potentially harmful substances in surface and groundwater. For example, the solubility of radioactive cesium ($137Cs^+$) may be limited at a nuclear disposal site due to humus.

c. Define erosion (water and wind).

Soil erosion is the loss of topsoil, surface litter, and other soil components, primarily due to the actions of flowing water or wind. Loss of topsoil reduces surface fertility, which in turn reduces plant coverage and the ability of plants to hold the soil-accelerating the erosion process. Wind erosion is experienced where dry, bare soil exists (as in the Great Plains Dust Bowl experienced in the U.S. Midwest during the 1930s) and usually contributes to less soil loss than does water erosion. Three types of water erosion occur. Sheet erosion occurs when uniform sheets (or layers) of soil are washed away due to a wide flow of water. Rill erosion is produced when rapidly flowing surface waters form rivulets, cutting small channels into the soil. Gully erosion results when the rivulets of rapidly flowing surface water combine with subsequent rains (usually on steep, vegetation-poor slopes), cutting wider and deeper channels (gullies). Soil erosion is usually less severe in forests and rangelands than on croplands, but soil resources in these areas recover more slowly than those on croplands[1].

d. Describe the following processes and explain how water and soil interact in each:

- Infiltration and percolation;
- Groundwater recharge;
- Run-off;
- Evapotranspiration; and,
- Unsaturated flow.

The flow of water through the environment is known as the hydrologic cycle. This cycle facilitates the dispersion of nutrients through the environment. The hydrologic cycle consists of evaporation, transpiration, condensation, precipitation, infiltration, percolation and runoff. Evaporation is the process of water being converted into water vapor and transpiration is the process of water being transported through a plants parts to be evaporated into the atmosphere (also known as evapotranspiration). Condensation is the formation of water droplets from water vapor. Precipitation is the deposition of condensed water vapor as dew, rain, snow, sleet, or hail. Infiltration is the movement of water into the soil. Percolation is the downward flow of water through soils and permeable rock layers into groundwater (this process is known as groundwater recharge). Runoff is the surface flow of water that does not infiltrate into the soil. Differences in energy with regard to free water as opposed to water in the soil as expressed per unit quantity of water is known as its potential. The downward flow of water through unsaturated soils is primarily due to its gravitational potential. Matric potential affects unsaturated soils and is the result of surface tension and adhesion of water to the surface of the soil. In addition, osmotic potential results from dissolved molecules and ions. Water usually moves from areas of high potential to areas of lower potential. However, water does not usually move from clay to sand-- even though the sand is drier, due to the higher adsorption properties of clay. In drier soils, water is more strongly held at lower potentials and is mainly restricted to narrow pores, resulting in the water flowing more slowly in unsaturated soils compared to the rate of flow through saturated soils.[1]

e. Describe how soil characteristics, slope factors, and land cover conditions impact the detachment and transport processes of pollution.

The transport of pollutants through the soil is dependent on physical soil properties as well as to the soil's chemical properties, which determine its ability to retain (adsorb) the chemical constituents of the pollutants. Water solubility of the contaminant is a large determinant in the release and transport of the contaminant in surface and groundwater. Usually, highly soluble chemicals tend to have a low adsorption potential with regard to soils and sediments and tend to be quickly and easily distributed by the hydrologic system. Dissolved pollutants being transported by surface waters mostly travel the route that the surface water flows, which is dependent on slope (among other factors). Transport of pollutants into the groundwater is dependent on the rate of percolation. Pollutants that are strongly adsorbed to soil particles are transported at the rate of soil erosion (i.e. transported with the soil particle). Land cover (vegetation) restricts the loss of soil particles to erosion and can lessen the subsequent transportation of pollutants into surface waters where highly adsorptive contaminants are concerned.

f. Discuss pollutant loading and the pollutant delivery ratio.

Pollutant loading and the pollutant delivery ratio describe the sorptive capacity of the soils and the rate of transmission of pollutants into the environment (i.e. by way of surface waters, and is characterized by using the modified universal soil loss equation (MUSLE) and sorptive partition coefficients for the pollutants of concern. MUSLE is an estimation tool that is used to approximate the amount of surface soil eroded in a storm event of a particular intensity. Sorption coefficients are required to project the amount of a pollutant transported in dissolved form.[2]

g. Discuss the use of soil survey maps.

A general soil survey map is color-coded to distinguish the major soil associations (groupings) present in the area of consideration. A general soil survey map depicts factors on a larger scale and is not suitable for obtaining information required for soil management at an individual site, but allows the comparison of larger areas of land for general land use determinations. In addition to depiction of soil associations, general soil survey maps often include three dimensional representation showing relationships between soils, parent materials, and landscape position for the major soils included in the soil survey.

For information pertinent to a particular site, selection of the appropriate map for the specific site from the "Index to Map Sheets" in the soil survey is required. Each map unit description includes soil information for common uses, major limitations or hazards, and possible alternates to remedy these limitations or hazards. Soil surveys facilitate the development of resource plans, but as each soil area on the map may consist of several soil types, onsite investigation is required for intensive use planning.[3]

h. Discuss the cation and anion exchange capacity of soils.

Cation exchange capacity (CEC) is defined as the ability of soil to sorb or hold cations and to exchange species of these ions in reversible chemical reactions. It is a quality important for both soil fertility-nutrition studies and for soil genesis. Thus, this type of data is widely used in soil classification considerations. However, its measurement is rather empirical, and several different analytical methods have been proposed. Despite the differences, CEC determinations yield numbers which are valuable in evaluating the capacity of soil to retain cations, its degree of weathering, and general chemical reactivity. The two types of CEC determinations that have been more widely employed are the ammonium saturation-displacement method commonly conducted at pH 7, and the summation method in which all exchangeable cation species are added. Some uses, inferences, and interpretations from CEC data are: (1) Inferences as to clay mineral species present in the soil; (2) Relative degree of weathering of the soil; (3) Agronomic and forest nutrition significance; (4) Engineering practice; and (5) Computing "percentage base saturation," a widely used pedologic and nutritional quality of soils.[4]

Anion exchange deals with the reaction of phosphate ions with various metals such as soluble iron, aluminum, and manganese and with insoluble hydrous oxides of these elements, such as limonite and goethite. The compounds formed as a result of fixation by iron and aluminum oxides are likely to be hydroxy phosphates. The large quantities of hydrous iron and aluminum oxides present in most soils make possible the fixation of tremendous total amounts of phosphorus by this means. Part of the phosphate that has reacted with iron and aluminum compounds and with silicate clays is subject to replacement by other anions. Such replacement is called anion exchange.[1]

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[1] Brady, Nyle C., *The Nature and Properties of Soils*, 8th ed., Macmillian Publishing Co., NY, 1974.
[2] Asante-Duah, D. Kofi, *Management of Contaminated Site Problems*, Lewis Publishers, Boca Raton, FL,1974.
[3] *The Surface Down-- An Introduction to Soil Survey for Aaronomic Use*, U.S. Department of Agriculture Soil Conservation Services, 1994.
[4] Buol, S.W., F.D. Hole, and R.J. McCracken, *Soil Genesis and Classification*, The Iowa State University Press, Ames, IA, 1973.

1.10 Environmental Compliance personnel shall demonstrate a familiarity level knowledge of the basic principles and concepts of hydrology.

Supporting Knowledge and/or Skills

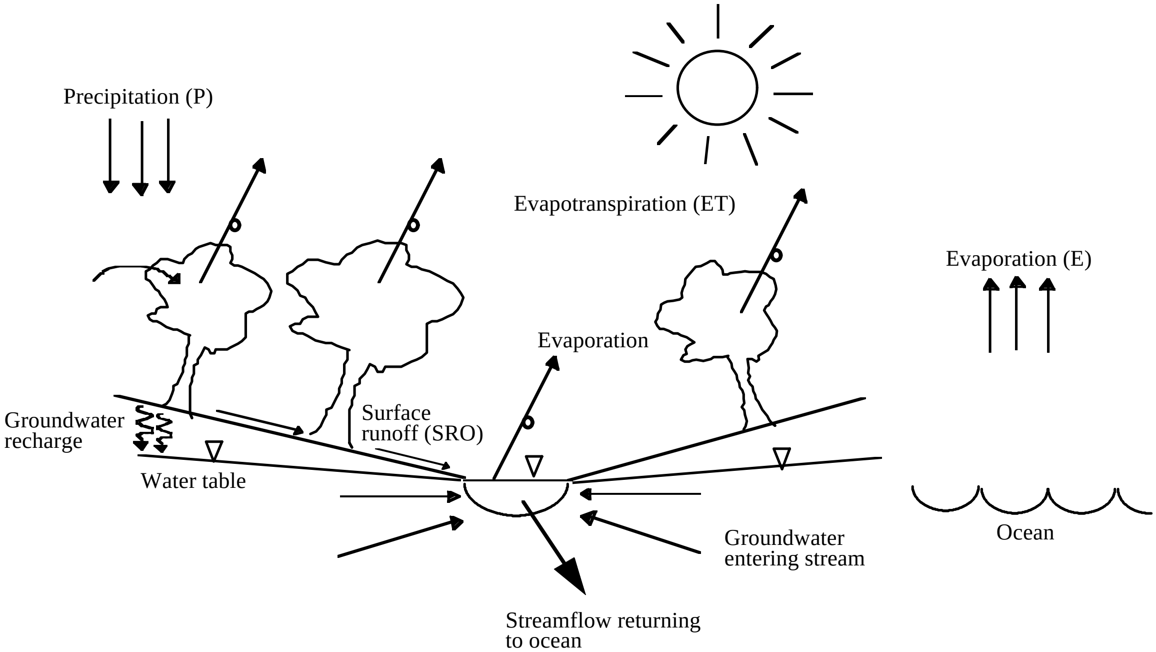
a. Define hydrology.

Hydrology is the study of the occurrence and distribution of water, both on and under the earth's surface. Hydrology studies the waters of the earth, their occurrence, circulation, and distribution, their chemical and physical properties, and their reaction with their environment, including their relationship to living things.[1]

b. Describe the hydrologic cycle.

The hydrologic cycle is a continuous process without beginning. Rain or snow falls as precipitation, some is intercepted by plants and buildings, and never reaches the ground. Some infiltrates into the ground, and some runs off over the ground surface. A large portion of the infiltrated water is taken up by plants and evapotranspirated back into the atmosphere. The remainder enters the saturated groundwater and eventually flows back to the surface water system. Some of the runoff flows into depressions, where it either infiltrates to the groundwater, or evaporates into the atmosphere. A portion of the original precipitation runs off into the stream network. Water is evaporated from the oceans and lakes and delivered again through precipitation by weather systems (Figure 1.10-1).[2]

Figure 1.10-1[2]



Hydrologic Cycle

c. ***Define the following hydrologic terms and describe the relationships between them:***

- Precipitation
- Steam flow
- Evaporation
- Transpiration
- Subsurface water
- Sedimentation

Precipitation is water droplets or ice particles that have condensed from atmospheric water vapor and are sufficiently massive to fall to the earth's surface as rain or snow. Several conditions must be met: (1) a humid air mass must be cooled to the dew point temperature, (2) condensation or freezing nuclei must be present, (3) droplets must coalesce to form raindrops, and (4) the raindrops must be of sufficient size when they leave the clouds to insure that they will not totally evaporate before they reach the ground.[2]

All surface and sub-surface water flows originate as precipitation. Evaporation and evapotranspiration return water vapor to the atmosphere to feed precipitation.

Stream flow is surface water which originated as runoff from precipitation or from groundwater sources and is moving down gradient. Most of this surface water either reaches the oceans, infiltrates into the groundwater, or evaporates. This part of the hydrologic cycle is the excess water which is not used by vegetation and/or cannot be retained as groundwater due to insufficient infiltration (runoff) or flows back to the surface as recharge to streams.

Evaporation is the conversion of liquid water into vapor, especially surface water into atmospheric water vapor. Water molecules are continually being exchanged between a liquid and atmospheric water vapor. When the amount of water passing into the vapor state exceeds the amount moving into the liquid state, evaporation results. Condensation is the opposite process and occurs when the air mass can no longer hold all of the water vapor that it contains.

Evaporation is the source term for the hydrologic cycle. Most of Earth's precipitation originates from evaporation of ocean surface waters. Transpiration (or evapotranspiration) is also like "evaporation" in that it is a method of returning surface water to the atmosphere, but in this case via living creatures.

Transpiration is the return of water to the atmosphere via living creatures.

In plants, transpiration is a product of photosynthesis as waste products are carried off through the stomata. Most of the vapor losses from a land-dominated drainage basin results from plant transpiration.[2] A much less significant source is from animals where the vapor is given off through the pores of the skin. Respiration is a similar process in animals that returns a small amount of water to the atmosphere. See evaporation, above, for effects on the hydrologic cycle.

Subsurface water (groundwater) is water that is below the earth's surface, which is a part of the saturated zone below the water table, especially that between saturated surface soils and rock layers.

The main source of groundwater is direct infiltration of precipitation and infiltration from collection depressions. This subsurface reservoir of water usually moves laterally (slowly) but sometimes is trapped in stagnant basins in low precipitation / runoff regions. Groundwater supplies wells and springs, and also recharges surface runoff directly.

Sediment is the material that settles to the bottom of a liquid. Sedimentation is the deposition of terrestrial materials that were transported either by air or water. Sedimentation is a byproduct of the hydrologic cycle where surface materials are transported to lake beds and ocean floors. Over geologic time, sediments have formed rock layers which determine the limits of groundwater movements due to their inherent permeability.

d. Define the following groundwater terms and describe the relationships between them:

- Capillary water
- Zone of saturation
- Specific yield
- Hydraulic conductivity
- Transmissivity

- Vadose zone

Capillary water is that water which is held in the capillary fringe above the water table by capillary attraction. It is distinguished by other types of water in the capillary fringe that are: (1) gravity water which is water moving by gravity through the capillary fringe toward the water table; (2) hygroscopic moisture is a thin film of water adhering to soil grains by molecular attraction and is not normally removed by usual climatic conditions; and (3) water vapor which is water contained in the air within the soil pore spaces.[3]

The **zone of saturation** is the groundwater area that lies below the aerated or vadose zone. The water table is at the top of the saturated zone, and it is referred to as an aquifer. The saturated zone is the groundwater zone in which water and, therefore, contaminants, are transported laterally. This movement of groundwater is what allows groundwater to play a role in the hydrologic cycle. Wells tap into the saturated zone when it lies below the surface of the ground; springs produce stream flow or recharge surface waters where the saturated zone meets the surface.

Specific yield is the ratio of the volume of water given up by gravity flow from a saturated mass of rock or soil to the volume of that saturated mass. This ratio is stated as a percentage. Specific yield is only part of the water contained in an aquifer. Some water is retained as specific retention. Water held in specific retention is similar to capillary water in the vadose zone.[4]

Hydraulic conductivity known as conductivity, is the rate of flow of water in gallons per day through a cross section of one square foot under a unit hydraulic gradient, at the prevailing temperature (gpd/ft2). In the International System, the units are m2/day/m2 or m/day. Hydraulic conductivity is governed by the size and shape of the pores, the effectiveness of the interconnection between the pores, and the physical properties of the fluid.[3]

Transmissivity is the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Transmissivity values are given in gallons per minute through a vertical section of an aquifer one foot wide and extending the full saturated height of an aquifer under a hydraulic gradient of 1 in the English Engineering system; in the International System, transmissivity is given in cubic meters per day through a vertical section of any aquifer one meter wide.[3]

Transmissivity is different from hydraulic conductivity because hydraulic conductivity is a measure of water passing through 1 square foot while transmissivity is a measure of water passing through a cross section of the saturated aquifer one foot wide in the English system.

The **vadose zone** is that area which is below the earth's surface and above the groundwater layer (water table). It is considered the zone of aeration. The vadose zone is a three-phased system comprised of soil, water, and air. Water is in both the liquid and vapor phase. Smaller capillary pores may actually be saturated in the vadose zone.[2]

This zone is significant to hydrology and especially to the environmental sciences in that water must pass vertically through this zone before it moves laterally as groundwater. It is in this zone that migration of contaminants becomes a critical issue that determines the overall environmental impact.

e. Define the following surface water terms

- Mass curve
- Frequency analysis

A **mass curve** is the cumulative plot of discharge versus time for a series of rainfall events. The mass curve, or summation curve method results in an S-shaped curve that is the result of an infinite series of runoff increments. The S curve is constructed by adding together a series of unit hydrographs, each logged with respect to the preceding one.[1]

A **frequency analysis** is an analysis conducted to determine the probability of precipitation. Precipitation records are often too short to permit reliable frequency analyses except for relatively short return periods typically of 10 years or less. In such cases reliable rainfall frequency values for longer return periods can be obtained by applying ratios of rainfall magnitudes for different return periods, say 100 to 10 year rainfall, computed from long-record stations with precipitation regimes similar to those of the short-record stations for which data are required.[1]

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[1] Potter (section by D.A. Hamilton), *Principles and Practices of Civil Engineering*, 1st edition, published by Great Lakes Press, 1994.
[2] Fetter, C. W. Jr., 1980, *Applied Hydrogeology*, Charles E. Merrill Publishing Co. Columbus, OH.
[3] Driscoll, Fletcher G., 1986, *Groundwater and Wells*, Johnson Division, St. Paul, Minnesota.
[4] Linsley, Ray K., M.A. Kohler, & J.L.H. Paulhus, 1975, *Hydrology for Engineers*, 2nd Edition, McGraw-Hill, New York.

1.11 Environmental compliance personnel shall demonstrate a familiarity level knowledge of the basic principles and concepts of geology.

Supporting Knowledge and Skills

a. Discuss the composition, identification, and properties of the following types of rocks:

- **Igneous**
- **Sedimentary**
- **Metamorphic**

Minerals are the building blocks of rocks. Rock forming minerals are generally defined as naturally occurring chemically distinct materials that have a defined, repetitive internal structure. A rock is usually an aggregate of one or more types of minerals. Rocks are divided into three types: igneous, sedimentary, and metamorphic.

Igneous Rocks

Igneous rocks are formed by solidification from a molten or partially molten magma. A magma is a naturally occurring mobile rock material, generated within the earth and capable of intrusion into the upper crust of the earth or extrusion onto the surface of the earth. Magma consists of a liquid melt phase and a number of solid phases of suspended crystals of various minerals. In some cases a gas phase also may be present. Below the earth surface, intrusive igneous rocks form from the injection of magma into zones of weakness or from the heating and melting of older rocks that have become deeply buried. Intrusive igneous rocks are characterized by larger crystals that have formed from the slow cooling and resulting slow crystallization process. Examples are granite, quartz monzonite, diorite, and gabbro. Extrusive igneous rocks are formed from magma that has been released in the liquid state to the earth surface typically by volcanic eruption. Extrusive igneous rocks are characterized by relatively small crystals that are formed by rapid cooling permitted at the earth surface. Examples are andesite, basalt, and pumice. In some cases the cooling process is so rapid that no crystals form and the resulting amorphous material is called obsidian.

Composition

The chemical makeup of the magma determines the mineralogical makeup of the igneous rocks that are derived from it. As a consequence of original cooling of the earth, chemical and mineral differentiation within the crust occurred. The differentiation process was largely driven by the temperature at which various minerals crystallize and the density of those minerals. The differentiation process resulted in heavier rocks forming the deeper, oceanic crust and lighter rocks forming the relatively shallow, continental crust. As a result igneous activity associated with oceanic crust is more typically associated with the formation of darker colored rocks that are composed of dense minerals. Typical of such rocks are those found in the lava flows of Hawaii. Basalt is typical of the igneous rocks that are associated with oceanic crust. The igneous activity associated with continental crust is more typically associated with rocks that are composed of less dense minerals.

Granite is typical of the igneous rocks that form in the continental crust. Extrusive and intrusive igneous rocks form from both oceanic and continental magmas.

Identification

Igneous rocks are identified by the types of minerals present. Igneous minerals are those that formed from a molten magma. Not all minerals can be formed by the process of solidification from the molten state. The texture of the rock is an important means of identification. Igneous rocks tend to have very little visible porosity. The solidification process that results in the formation of the igneous rock causes the crystallizing minerals to grow together in a solid mass. Some types of minerals have a great propensity to form well defined mineral shapes, while other minerals fill intercrystalline spaces without developing well defined crystal faces. However, those magmas that contain a gas phase may result in the formation of highly porous igneous rocks. These rocks usually have very small crystals and a jagged appearance due to the rapidity and violent nature of their formation. Pumice is an example of a porous igneous rock.

Igneous rocks tend to be harder than other types of rocks. The minerals from which igneous rocks are formed are typically hard and this hardness is conveyed to the rock. Intrusive igneous rocks tend to form in large irregular blocks often in the uplands of mountain ranges. Therefore, the lack of appearance of tabular bedding associated with sedimentary rocks may indicate igneous rocks. However, some intrusive igneous rocks may have been injected between layers of sedimentary rocks and, subsequently, have the same layered occurrence as the rocks around them. Extrusive igneous rocks may also have a layered appearance if they were extruded on a reasonably flat surface.

Properties

Igneous rocks have a wide variety of properties because of the difference in the magma from which they formed, from the method of their formation, and from the effects of weathering after formation. Igneous rocks are usually not good aquifers because they have very little porosity. However, they can transmit water very efficiently if they are highly fractured. In such cases they may serve as a conduit through which groundwater can move from a source or recharge area to a discharge area.

Sedimentary Rocks

Sedimentary rocks are formed by the lithification of sediments usually in layers under relatively low temperature and pressure at or near the earth surface. Sedimentary rocks may also form from the precipitation of minerals such as calcite from a sea water brine.

Sediments are derived by the processes of weathering of other rocks and are transported to other areas by the action of wind, water, ice, and gravity. Sediments, once transported, are deposited as loose materials, generally in layers, that may eventually become solidified. Most sedimentary deposits are associated with the action of water. Slow-flowing or standing water will deposit sediments that have been carried by faster moving water. Where conditions are favorable for deposition, layers or strata gradually accumulate. As accumulations thicken, pressure from above compacts the underlying sediments and squeezes out much of the water contained in the sediments. Inter-granular chemical reactions and reactions with the dissolved constituents in the water results in cementation of the sediment particles into a lithified mass or sedimentary rock.

Sandstone and conglomerate are examples of sedimentary rocks that are formed from sand and gravel deposits. Shale is the sedimentary rock that forms from clay deposits. Limestone and dolomite are the typical sedimentary rocks that form from the precipitation of minerals from a sea water brine.

Composition

The composition of sedimentary rocks vary considerably. This is due to the variability in the sources of the sediments and the weathering impacts on those sources. Sediments may consist of various sizes, mineral compositions including organic compounds, and have a variety of physical properties.

Sandstone and conglomerate are two typical types of sedimentary rocks. They are characterized by particles of sand and gravel that have been lithified. The sand and gravel particles usually have a high quartz content but can contain a variety of other minerals most typically feldspar. Shale is another type of sedimentary rock. It forms from the compaction of clay particles. Clay is formed from chemical reactions resulting from the weathering of minerals found in igneous and metamorphic rocks. Limestone and dolomite are sedimentary rocks that form from chemical precipitation from sea water brines. Limestones can also contain large amounts of shells from marine animals.

Identification

Sedimentary rocks are identified by typical layered character that results from the method of sedimentary deposition. Sedimentary rocks can usually be found in relatively thin but laterally extensive strata. These strata are usually layered to form thick sequences of rock that reflect a variety of successive environments of deposition.

Unlike igneous rocks, sedimentary rocks usually result from processes that tend to weather away less chemically and physically stable minerals. As a consequence sedimentary rocks usually consist of only a limited number of very stable minerals.

Some sedimentary rocks contain fossils. The appearance of fossils is an almost absolute indication of sedimentary origin. Igneous and metamorphic processes so completely change source materials that fossils are not preserved.

Properties

Sedimentary rocks are the softest and most pliable of the rock types. Sediments are held together less firmly than the minerals in igneous and metamorphic rocks. Even though sediments such as quartz can be very hard, the rigidity of sedimentary rocks is reduced because of the cementation that holds the sediments together. Shale can be very soft because it is composed of clay.

Sandstone, conglomerate, and some limestones can be highly porous and may be very good aquifers. These rocks can also be highly fractured or in the case of limestone can contain caverns that will transmit water very rapidly. Shale is usually very impermeable and typically forms good aquitards or barriers to ground-water flow. However, hard highly lithified shale may be extensively fractured and, thereby, becomes a good transmitter of water.

Metamorphic Rocks

Metamorphic rocks are rocks that have had their original form altered by one or more geological processes (such as heat, pressure, and chemical action). Due to alteration, the rock is changed (metamorphosed) into a rock with different texture, structure, mineral composition, or general appearance. The original chemical composition of the rock, however, remains unchanged through the alteration process because there is usually no movement of materials in or out of the altered rock mass. High grade metamorphism is due to intense heat and pressures deep beneath the earth surface.

All types of rock (igneous, sedimentary, and metamorphic) can be subjected to sufficient heat and pressure to alter their structures. As a consequence, all rocks have a metamorphic equivalent. The metamorphic rock type depends on the original rock characteristics and the nature, intensity, and duration of the metamorphic activity that it has undergone.

Metamorphic rocks are the least common of the three rock types found on the earth surface. They are more often found below the surface, deep within the crust. When they are exposed, it is usually due to tectonic activity that has resulted in uplift.

Examples of metamorphic rocks are gneiss, schist, slate, and marble. Gneiss and schist typically form from the metamorphism of quartz and feldspar rich parent rocks. Slate forms from parent rocks rich in clay minerals. Marble forms from limestone and dolomite parent rocks.

<u>Composition</u>

The composition of metamorphic rocks is dependent on the composition of the parent rock. The chemical composition is not changed from the parent rock because no net movement of material into or out of the rock mass usually occurs. However, the mineral composition is frequently changed with the formation of minerals that are stable at higher temperatures and pressures.

<u>Identification</u>

Metamorphic rocks show evidence of change resulting from the processes of heat and pressure. As a result, some metamorphic rocks may be identified by distortions in shape, through separation of minerals within the rock especially into bands or swirls often of different colors, and through bending of layers within the rock (not to be confused with folds of rocks layers that are discussed below).

Properties

Metamorphic rocks, because of the variety of parent rocks and the differences in time and intensity of metamorphic processes to which the parent rocks have been subjected, exhibit a variety of properties. Intense metamorphism results in high grade metamorphic rocks that are similar to some intrusive igneous rocks such as granite. Less intense metamorphism may not change the character of the parent rock very much at all. Harder, higher grade metamorphic rocks may be highly fractured and, therefore, may be good transmitters of groundwater. Lower grade metamorphic rocks are usually not highly fractured and because of their low permeability can be poor ground-water transmitters. Marble, the metamorphic equivalent to limestone, can be a good transmitter of groundwater when caverns or fractures are present.

b. Describe the geometry and properties of the following rock masses:

- Folds
- Faults
- Structural discontinuities
- Shear strength of discontinuities
- Residual stress
- Sheet joints

Folds

Folds are undulations or waves in the rocks. Folds are best displayed in stratified rocks such as sedimentary and volcanic rocks, or their metamorphosed equivalents. However, any layered rock, such as banded gabbro or gneiss, may display folds. Folds may be developed over very small distances of less than an inch, be several feet or even miles across. Folds can even have continental proportions of several hundred miles.[2]

Anticlines are folds that are convex upward. Anticline, in Greek, means “opposite inclined”. It refers to the characteristic, in the simplest anticlines, of the two sides or limbs being inclined or dipping away from each other. In anticlines the oldest rocks are exposed at the center of the fold. Anticlines generally result from compressive forces that push the earth surface together.

Synclines are folds that are concave upward. Syncline, in Greek, means “together inclined”. It refers to the characteristic, in the simplest synclines, of the two limbs dipping toward each other. In synclines, as opposed to anticline, the youngest rocks are exposed at the center of the fold.

These simple folds can be greatly complicated by forces within the crust. Folds can be overturned such that the limbs actually dip in the same direction. They can be repeated forming a series of alternating anticlines and synclines.

In a plateau area, where strata is relatively flat, the strata may locally assume a steeper dip. Such a fold is a monocline. The beds of a monocline may dip a few degrees to 90 degrees, and the elevation of the same bed on opposite sides of the fold may differ by several hundred to thousands of feet.[2]

Goundwater tends to flow within permeable strata that act as aquifers and tends to be confined by less permeable strata that act as aquitards. Flow is, therefore, controlled by the permeable character of the various layers of the subsurface. The difference in elevation between the recharge area and the point of discharge is the force referred to as the head that causes groundwater to flow. Therefore, flow tends to follow the topographic surface with groundwater flowing from the highest point, the recharge area, to the lowest point, the discharge area. In unfolded rocks groundwater flows along permeable beds to a point of withdrawal such as a spring, water body, or pumping well. This flow is disrupted by strata that are dipping and flow may be channeled in some other direction than that which would be expected based on the topographic surface. Flow may be directed around an anticline if the oldest rocks (the rocks at the center of the fold) are less permeable than those in the limbs. Therefore, it is the permeability differences in the different strata and the relative positions of these strata that control ground-water flow around or through folds. Each case must be analyzed individually to determine how the fold geometry and the permeabilities of the rock strata direct ground-water flow.

Faults

Stress placed on rocks results in deformation. If the deformation caused by the stress proceeds far enough, the rocks eventually fail by rupture. Failure by rupture is expressed in the rocks of the outer shell of the earth’s crust by joints, faults, and some kinds of cleavage.[2] Rocks are characteristically broken by smooth fractures known as joints. Joints may be defined as divisional planes or surfaces that divide rocks, and along which there has been no visible differential movement of the rocks parallel to the plane of the joint. A fault occurs when differential movement in a direction parallel to the plane of the joint has occurred. If movement at right angles to the joint surface takes place the resultant feature is called a fracture.[2]

The attitude of fault planes that result from horizontal tensional and compressional forces is usually not vertical. Therefore, the rock on one side of the fault is essentially beneath the fault plane. The rock beneath the fault plane is called the foot wall and the rock above the fault plane is the hanging wall. Faults result from either tensional or compressional forces. Tensional forces result in a lengthening of the rock mass. Lengthening the rock mass causes distinctive relative movement along a fault plane. If a fault occurs as a result of tensional forces, the relative movement of the hanging and foot walls is for the hanging wall to move downward relative to the foot wall. Such a fault is called a normal fault. Compressive forces tend to shorten the affected rock mass. Movement along a fault resulting from compressional forces is for the hanging wall to move upward relative to the foot wall. Such a fault is called a reverse fault. Thrust faults are a special case of normal faults in which the angle of the fault plane is particularly low. The relative movement along a thrust fault plane can be extensive resulting in considerable crustal shortening.

Shearing stress may be imposed on a rock mass. Shear stress results in lateral movement along the fault plane of the rock masses relative to each other. Such faults are called strike slip faults. Strike slip faults can have a vertical plane.

Faults, fractures, and joints can have considerable impact on ground-water movement. Open fractures obviously offer an easy route for water movement. Fractures are the principal method for movement of groundwater in igneous and most metamorphic rocks because these rocks are usually not porous. However, fractures usually do not have large volume and, consequently, do not hold large volumes of water. Therefore, water will move quickly through fractures but the volume of water involved will be small unless the fractures either have wide openings or the fractured rock is porous or in contact with porous and permeable rocks. Faults may have a variety of hydraulic properties. Faults that form from compressional forces may actually seal existing permeable rocks. The compressive force in these cases causes the minerals along the fault plane to recrystallize and fill the existing pore space. Faults and fractures may have been conduits for mineralized solutions. These solutions could have deposited sufficient minerals in the fault or fracture to completely fill the void and essentially seal it to further ground-water migration.

Structural Discontinuities

Discontinuities in rocks are characterized by an abrupt change in rock type. If strata suddenly end against different rock beds, a fault may be present. Discontinuity of rock structures is characteristic of faults, but is not proof of faulting unless other possible interpretations are eliminated.[2] Fault related discontinuities occur when movement along a fault results in dissimilar strata coming in contact with each other across the fault plane.

Structural discontinuities can impact ground-water movement. Abrupt permeability changes can occur at a structural discontinuity if the permeability of the rocks on either side of the fault plane are greatly different. An increase in ground-water mobility can occur if a saturated low permeability rock is in contact with a high permeability rock through such a discontinuity. This may result in unexpected movement of contamination.

Shear Strength of Discontinuities

Shear strength of a rock mass is the resistance of that mass to deform by slippage along an internal plane. Shear strength of a discontinuity is the mutual resistance of the two rock masses on either side of the discontinuity to slip along the plane of the discontinuity. Shear strength is a function of the discontinuity geometry and other characteristics related to its genesis. A highly undulating plane of discontinuity would have more resistance to movement than would a flat plane discontinuity. A discontinuity along a normal fault that resulted from tensional stress may be weaker than one along a reverse fault that resulted from compression stress because of the increased pressure from compression may have effectively welded the rocks across the discontinuity together.

In other types of discontinuities rock masses may have been invaded by dikes of rocks that are less resistant to weathering. In these cases the dikes, because of increased weathering, may be weaker than the invaded rocks and the shear strength of the discontinuity will be low.

The shear strength of the discontinuity will in itself not impact ground-water movement. However, if the discontinuity is characterized by hard impermeable rocks or rocks that have been highly recrystallized by the forces that resulted in the discontinuity, ground-water movement may be impeded. Also, if the discontinuity is highly weathered and the weathering results in conversion to clay minerals, the movement of groundwater may be impeded. On the other hand if the discontinuity is characterized by highly fractured rocks that have not been welded by recrytallization, ground-water movement may be enhanced.

Residual Stress

Residual stress is the stress that remains in the rock mass after some release in stress energy has occurred. Such a release may be associated with movement along a fault during an earthquake. An earthquake occurs when the stress within the rock mass exceed its elastic limit. Movement occurs and some part of the energy associated with the stress on the rock mass is released. In general, not all of the energy may be released and that which remains is the residual stress. In tectonically active areas, stress continues to build until another earthquake occurs.

Another example of residual stress is stress in a rock mass that remains after a glacial mass has been removed by melting. The weight of a glacier pushes the underlying rock mass downward. The elevation of the rock mass is actually depressed under the weight of the glacier. After the glacier melts, the depressed rock mass rebounds through a process of isostatic readjustment. Isostatic readjustment lags behind the unloading of the crust caused by the melting glacier. The lag is a result of the time necessary for material deep in the crust and the upper part of the mantle to move under the area of reduced load.[2] The rocks within the crust are under a residual stress after the glacier melts but before they return to isostatic equilibrium.

Sheet Joints

Sheet joints, or sheeting, are somewhat curved joints essentially parallel to the topographic surface. The joints are close together near the surface, in many places the interval between joints may be only inches. The intervals between the joints increases with depth and a few tens of feet below the surface sheeting disappears. Sheeting is best developed in granite-like rocks but can occur in sandstone.[2]

The effects of sheet joints on ground-water flow is similar to that of fractures. However, sheeting effects will only be noticed in groundwater within a few tens of feet of the surface where sheet joints exist.

c. ***Discuss the use of geological and geotechnical maps.***

Geologic and geotechnical maps illustrate stratigraphic and structural relationships between rock units exposed at the surface and are used for geological investigations (e.g., mineral and ground-water investigations) and geotechnical investigations (e.g., siting dams, power plants, buildings, slope stability studies, etc.). Geologic cross-sections drawn through select areas of the map allow the geologist to construct a three-dimensional view of the subsurface by extrapolating the rock units to show their structural and stratigraphic relationships at depth and, in some cases, in the air, as they would appear if not eroded. Geologic maps and associated cross-sections can be used to show and interpret the structural and stratigraphic influences upon ground-water systems (confined and unconfined), slip surfaces of landslides, and detailed descriptions of the geotechnical properties of the rock units.

d. Describe the geologic considerations, criteria, and procedures used to evaluate the following areas of topography:

- Relief
- Slope stability
- Flood plains
- Karst terrain

Relief

Topographic relief is the elevation difference between the highest and lowest points on the land surface in a given area. Relief considerations may be import to slope stability. In areas of high relief and unstable rocks or soils, landslide hazards will exist. Buildings and other cultural features will be threatened by any disturbance to the unstable slopes. Saturated ground-water conditions will aggravate the hazard by reducing the geostatic pressure between soil and rock fragments that holds the slope in place. Construction activities will generally result in steepening of some slopes also causing some increase in hazard.

High relief may result in increased mass wasting. Mass wasting is the natural downslope movement of surface materials. The potential for mass wasting can be assessed by geologists and engineers by evaluating the characteristics of the site, the conditions present such as soil and rock type, the degree of saturation, and the proposed actions.

Slope Stability

Mass wasting is also a concern when slopes demonstrate instability. Slope stability is strongly influenced by the amount of water present in the subsurface. The greater the volume of water, the more unstable the slope.

Mass wasting movements are categorized as: (1) Slips – descending material remains coherent and moves along one or more well-defined surfaces; (2) Falls – material free-falls or bounces down slope; (3) Slides – descending material moves along a plane that is roughly parallel to the slope of the surface; and (4) Slumps – material moves along a curved surface, with the upper part of the mass moving downward as the lower part moves outward.

The stability of the slope can be assessed by the same kinds of evaluations that assess the hazards of topographic relief. The conditions to be evaluated are the subsurface materials present, their condition, and the amount of moisture present as well as the activities that are planned for the area.

Flood Plains

Flood plains are formed by the erosion and deposition of sediments along either side of stream and river channels that occupy valleys of low topographic relief. Flood plains are broad valleys that are covered by alluvium. They are subject to occasional seasonal flooding. Depositional features exhibited in flood plains are bars, natural levees, and meander features.

Remediation of contaminated sites in flood plains are of concern because of the potential flooding that can result in further migration of contaminants in soils and surface and groundwater. Groundwater is typically very close to the land surface in flood plains. As a consequence, groundwater is easily contaminated. Ground-water flow rates may be relatively low because of the low hydrologic gradient and the presence of relatively impermeable clays in many deposits. However, sands associated with the stream channels and sand bars may have a relatively high permeability.

Karst Terrain

Karst terrain is associated with areas of thick limestone and dolomite strata near the land surface. These types of rocks can be dissolved by groundwater to form caverns of various sizes. Karst terrain is characterized by the presence of many sink holes and a system of underground streams flowing through solution passages in the rock. Sinks holes form when underground caverns become so enlarged toward the land surface that a surface depression develops.[3]

Ground-water movement in karst terrain is somewhat typical of groundwater flow in fractured rock. The limestone and dolomite in which the caverns are developed usually has relatively little porosity but the caverns can contain a large volume of water that is able to flow at a very high rate. However, groundwater that is not in contact with the caverns will not be very mobile.

e. Discuss weathering and its significance in geotechnical engineering.

Rocks undergo continuous processes that result in their weathering. Weathering processes can be mechanical (physical disintegration of the rock) and chemical (decomposition of the rock). Weathering is a key factor in the geologic processes that shape the surface of the earth. It results in the destruction of high exposed areas and creates sediment that holds moisture in low lands that are the habitats of much life. Weathering is the process of change that results from the exposure of rocks to air, water, changes in temperature, and other factors at or near the earth surface.

Mechanical weathering processes include:

(1) Frost action, which is caused by water freezing and thawing within fractures and pores of the rock. Frost wedging is caused by water freezing and expanding in

fractures prying the rock apart. Frost heaving is caused by water freezing beneath rocks and soil, lifting them;

(2) Abrasion is caused by the grinding action due to friction and impact associated with the transportation of rocks and sediment by water or wind, and by the action of glaciers;

(3) Pressure release results from the reduction of pressure on rocks. Pressure release is caused by the erosion of overlying rocks or the melting of glacial ice. The release of pressure causes sheet joints as previously discussed; and,

(4) Growth of plant roots and animal burrows which also causes mechanical weathering.

Chemical weathering processes result from the reactions of chemicals in water and air with rocks. Oxygen is abundant in the atmosphere and dissolved in water. It is active chemically and often combines with elements and compounds including certain minerals found in rocks exposed to the earth surface. Leaching is a common chemical reaction that occurs in water solutions. Leaching is the process of the dissolution of minerals into water. The formation of caverns by the dissolution of limestone has been discussed and is a process of chemical weathering. Hydration is another chemical process that occurs in water. In this process water molecules combine chemically with minerals to form new compounds. This process usually results in swelling. The increased volume forces the rock mass apart and causes concentric rock slabs to spall away from the rock mass in a process called exfoliation.

f. Discuss tests that assess weatherability.

Chemical alteration produces the effect of preconsolidation by changing the physiochemical bonds between the clay particles or by introducing stresses by the expansion or contraction of the grains during the alteration process. Most residual soils and weathered rocks exhibit this kind of preconsolidation. The preconsolidation load can be estimated from the stress-void ratio curve. Preconsolidation is extremely important in foundation engineering. A soil that is inherently compressible usually will not settle appreciably until the stress imposed by the structure exceeds the preconsolidation load.

The triaxial shear test is considered to be the most reliable strength test; the sample is subjected to confining pressure (application of axial stress or hold axial stress constant and increase confining pressure) until sample fails in shear. Weathering reduces the strength, increases the compressibility, and reduces the rigidity of intact rock.

g. Describe the process for logging rock cores.

Use a graphic log format that visually expresses the stratigraphic succession for describing continuous cores and drill cuttings. These logs should contain the following information:

- Thickness of rock units, scale of 1 inch equal 5 feet or as appropriate;
- Grain size, terrigenous clastic grain sizes and carbonate rock types using appropriate classification system (e.g., Unified Soil Classification System,

Modified Wentworth Scale, Clastic Limestone Classification, Classification of Limestones According to Depositional Texture);

- Textural Maturity: detrital clay content, sorting, roundness;
- Sedimentary Structures: e.g. bedding, laminations, ripples, flow structures, etc.;
- Accessories, such as fossils, diagenetic features (cementation, mineralization, density, etc.);
- Lithologic Name and type of contact (sharp, gradational, etc.) between different lithologies;
- Moisture Content;
- Fracturing (describe pattern or type);
- Porosity estimate (with hand lens); and,
- Color using the GSA Rock Color Chart.

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[1] Howell, J.V., *Glossary of Geology and Related Sciences*, 2nd ed., American Geological Institute, Washington, D.C., 1966.
[2] Zumberge, James K., *Elements of Geology*, John Wiley and Son, Inc., N. Y., 1965.